Canada. Conservation, Commission of.

INSTRUCTIONS

RELATING TO THE GATHERING OF CERTAIN

PRELIMINARY INFORMATION

RESPECTING

WATER-POWERS

PREPARED BY

ARTHUR V. WHITE, M.E.
Commission of Conservation, Canada

[General publications]

[G-6]

OTTAWA
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☛ This pamphlet may be had upon application to the Secretary, the Commission of Conservation, Ottawa; or to the Department of Lands, Victoria, B.C.

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NOTE

While conducting investigation relating to the water-power resources of Canada, the author of this brief pamphlet has often felt the need of having for distribution, and in concise form, a brief statement which would serve to set forth, in simple terms, some of the fundamentals which should govern in the gathering of preliminary information respecting water-powers.

Some of the Provincial Governments are making special investigations of their water-power resources. The Government of British Columbia, for example, has just organized (1912) a Water-Power Branch which will conduct hydrographic examinations of detailed and special character.

The Commission of Conservation, Canada, have in hand the making of a preliminary investigation of inland waters. This investigation permits the use of reconnaissance methods, by means of which knowledge may quickly be had respecting the general character, magnitude, and locations of the water-powers of the country.

The present pamphlet has been prepared—somewhat hurriedly—to meet pressing needs arising in connection with the water-power research being made by the Commission in the summer of 1912 in the Province of British Columbia. The pamphlet is intended to be only a brief suggestive guide to those who are interested in the collection of preliminary data relating to inland waters. If need so requires, the scope of the pamphlet, at some future time, could be extended.

It is believed that if a little special study is given to the subject of inland waters by those entrusted with the administration, or engaged upon the survey of government lands, such study will evoke in many persons an interest in our water resources, and in turn this will prove to be a stimulus which will result in the observation and recording of much information respecting water-powers, the acquisition of which information might otherwise be delayed.

A. V. W.

WATER-POWERS

Instructions Relating to the Gathering of Certain Preliminary Information Respecting Water-Powers

A Brief Statement setting forth some Requirements respecting the Gathering, in the Field, of Certain Data appertaining to Inland Water Resources, and designed to be a Guide to those Persons who may assist with such Work

THE inland water resources of the Dominion of Canada are of unique and exceptional value, and exist as a widely-distributed national asset.

During the last few years great attention has been given to the utilization of inland waters. The ability to transmit electrical energy long distances has resulted in an enhancement in the values of water-power sites, which in turn has caused persons interested in water-power developments to use, or seek to use, large quantities of water in special ways and for special purposes. Since it is necessary to conserve the common interests of the people in these waters, it is the desire and intention of the Federal and Provincial Governments of Canada, as quickly as possible, to obtain, so to speak, a preliminary inventory of the possible water-powers and other water resources of the country.

In pursuing this work, it is very desirable to have the sympathetic and practical co-operation of surveyors, engineers, fire wardens, game wardens, road superintendents, timber cruisers, and others, in assisting to assemble reliable preliminary data relating to the inland waters of Canada.

The data thus obtained will greatly assist the various Governments in administering and conserving, in the general public interest,

the water resources of Canada, and further, the publication of information relating to our water-powers will, no doubt, materially contribute to the commercial opening up and development of the country.

It may be remarked that the commercial opening up and development of Canada's resources—and to which power is so necessary—will greatly improve the field of engineering activity. This remark is made in order to suggest the fact, that hydrographic information gathered by engineers and others, when collectively published, will result in attracting the attention of capital to these water-powers and other resources; and one of the first classes in the community to feel the benefit of such new development is the engineer. Engineers who may be able to assist upon the gathering of the data desired may, therefore, find additional incentive in knowing that their pioneer work will, later on, result in the expansion of the sphere of their operations.

One of the chief objects in acquiring data respecting water-powers is, first, to enable the owners of the rights to know the possibilities and limitations of their powers, and thus arrive at some judgment respecting their possible uses and value; and, second, to enable prospective promoters of water-power development to learn the general possibilities of various powers without the necessity of costly, independent, preliminary surveys. Certainly, if the Crown be the owner of water-powers, it is of the utmost importance that it be informed, beforehand, upon all important facts connected with its water resources.

COMMISSION OF CONSERVATION, CANADA, MAKING INVESTIGATIONS

The natural resources of Canada are being investigated by the Federal Government through the Commission of Conservation, Ottawa. This Commission has recently (1911) issued an extensive report, entitled *The Water Powers of Canada.* It was not possible, in the time available before the publication of this report, satisfactorily to gather data respecting the water-powers of British Columbia, Alberta, Saskatchewan, and Manitoba. The Commission, therefore, decided to prepare and issue, as soon as practicable, a report dealing with the water-powers of Western Canada. Work incident to this report has already been commenced.

GUIDING PRINCIPLES

In order to assist to a better appreciation of the general subject of water conservation, it is deemed profitable here to make a few remarks along the lines laid down in the recent report of the Com-

mission of Conservation of Canada, entitled *Water Powers of Canada.* This report, which is freely quoted in what follows, points out that *precipitation* by rainfall, or snowfall, virtually constitutes the only source of inland water supply. Speaking broadly, of the annual precipitation upon the earth, about one-half is evaporated; about one-third is "run-off"—that is, it runs off over or through the ground, and eventually reaches the sea; and about one-sixth either joins the ground water, or is taken up in plant structure, or is otherwise absorbed in processes incident to the ground. The natural and cultivated properties of the land on which the rain and snow fall largely determine the efficient uses to which precipitation is applied. It is in this connection that forests are so indispensably associated with the precipitation, and hence with water as a natural resource. Whatever opinion may be entertained respecting the effect of forests in influencing the amount of precipitation, the burden of opinion is that no feature of the topography of the country ministers more efficiently to the gradual and economical run-off from the precipitation than do forest areas. Thus it is that failure to intelligently conserve forest areas has wrought havoc by causing a great destruction of forest floors and agricultural lands, which, humanly speaking, can never be restored, to say nothing of the annual destruction to property by flood run-off, which seems yearly to increase rather than diminish. The run-off is the chief factor entering into water-flow problems as they relate to power development.

A deforested, eroded, and scoured territory, which has lost the humus of the soil, cannot retain the beneficient rains which, instead of being retained in the ground and transmuted into plants by the various processes of growth, carry destruction in the pathways of their torrential run-off. The water is necessary to the soil, and the soil, with its plant growth, is necessary to an economical disposition of the water. The interests of municipal and domestic water supply, water for manufacturing and industrial purposes, irrigation, navigation, and water-power are all interrelated and interdependent. They all depend on the same natural source—*precipitation.*

In the case of water-power developments, therefore, it would be well to consider whether or not the industries which might use the water-powers would prove to be a menace to the district of their proposed location, and thereby spoil the watershed or waters for other necessary uses. Thus, wood-pulp mills, for example, which might completely denude the timber lands of trees at or near the headwaters

of important waterways had better not be established at all; or if established, then only under the strictest regulation and supervision designed to conserve the forest growth.

Along this line, therefore, in some instances, it may be possible for the engineer, or observer, when making his observations, to indicate what he thinks this or that particular water-power might be used for; whether, we shall suppose, for municipal purposes to serve a neighbouring town or settlement, for mining, for manufacturing wood pulp, or, etc. Sometimes some such remarks prove to be suggestive to persons seeking opportunities for industrial development.

POLLUTION BY FACTORY WASTES

The effects likely to result from the pollution of waterways by the waste products emitted from the industries utilizing power from these waterways are also very important factors for consideration. The maintenance of a pure and sufficient domestic water supply is a vital consideration; and, hence, a class of industrial waste products that will destroy life in the waters into which they are turned must be regarded seriously in their probable influence on human life. If any special instances of stream pollution are observed, it would be well to make a memorandum of such facts. When one realizes how even a great waterway like the Great Lakes System has been polluted, too great caution can hardly be exercised to conserve the purity of our inland waters.

WATER-POWERS REQUIRE CLASSIFICATION

The amount of water-power is determined by two factors: first, the hydrostatic head, or the vertical distance through which the water may fall; and, second, the amount of water which may be made to operate upon the water-wheels. There are, however, many characteristic features associated with water-powers, which differentiate one power from another, and which determine the commercial and economic values of the individual powers. It is as unreasonable not to differentiate between water-powers as it would be not to differentiate between timber tracts, mineral lands, or the items of any other natural resource varying in quantity, quality, and situation.

In presenting water-power information, effort should be made to make brief remarks upon features which may have special bearing upon any specific possible power sites.

By way of illustration, it may be remarked that the St. Lawrence River, owing to the vast storage capacity of the natural reservoirs

found in the Great Lakes, has the most uniform flow of any large river in North America or, probably, in the world. Therefore, other conditions being equal, water-power developments on this river will be of very much greater value than developments on a river subject to such great variations of flow as take place, for example, on the Mississippi. Inasmuch, therefore, as the uniformity of the flow of water greatly affects the values of water-powers situated upon various water-courses, it would be fitting for the observer, or engineer, to note any features that might appear capable, or appear to be made capable, of contributing towards uniformity of stream flow.

RESERVOIR SITES

In connection with the subject of uniformity of flow, one may be on the lookout either for natural reservoirs, such as lakes, or river expansions, or for natural sites where reservoirs may be created by means of dams. In such reservoirs the run-off from precipitation may be impounded, and subsequently discharged gradually throughout the year. Water-powers situated within the range of the direct influence of such natural storage reservoirs may be of incomparably greater value than other water-powers not so favoured.

When the subject of storage reservoirs is under consideration, it should not be forgotten that Nature also stores her waters elsewhere than in lakes and rivers. Forest floors, extensive areas covered with plant growth, soils and sub-soils, the gravel-beds of streams, and the great swamps of the country, each and all, constitute valuable water reservoirs. In such reservoirs there is a widespread and satisfactory distribution of waters, which enables Nature to yield her supplies gradually and as required. A discreet conservation and utilization of such reservoirs will, in general, be found to be much more desirable than some of the large artificially constructed reservoirs, where the liability of accidental destruction of large construction works is always more or less of a menace.

In passing, it may be noted that where an early selection of reservoir sites is made, and the same held under Government control, so that no settlement, railway construction, or other similar improvement, is allowed to take place upon such reservoir sites, the expense and trouble incident to future reimbursement for expropriated properties will be avoided. Hence the desirability of the Government having knowledge of the existence of such sites.

ACTUAL MEASUREMENTS REQUIRED

When information regarding water-powers is to be gathered, it is extremely important that the data be sufficient, and of the class that will enable a sound opinion to be formed upon the general water interests involved.

But little confidence can be placed in any reports of water-powers not based upon actual measurements, for, without measurements, the best judgment of explorers, and even of engineers, as to the heights of falls and the amounts of water discharging over them, is frequently very wide of the results disclosed by actual measurements.

This is well illustrated by an experience related by the engineer in charge of much of the field-work of stream-gauging for the Hydro-Electric Power Commission of the Province of Ontario. This engineer stated that prospectors who had been at the falls on the Kawashkagama River told him, in good faith, that the falls were capable of developing 30,000 horse-power at low water; and he was further assured by a surveyor, who claimed familiarity with what he was speaking about, that the Kawashkagama River was able to yield as much power as the Kaministikwia River. After a hard journey, the engineer arrived at the falls, and, instead of the 30,000 horse-power reported found the 317 horse-power given for the Kawashkagama River in the report of the Hydro-Electric Power Commission! If these prospectors had published a report of their mining or geological investigations, and incidentally mentioned that 30,000 horse-power could be developed at low water on the Kawashkagama River, such an assertion would have been very misleading.

RECONNAISSANCE SURVEYS

When knowledge of the quantities of water-power that may be available in particular places is required on short notice, and when sufficient records of actual observations do not exist, it is possible to *estimate* the probable amounts of power available. For such preliminary estimates, data are secured by what may be termed a reconnaissance survey of the general situation; but it must be recognized that the conclusions reached by such methods are not comparable with the results deducible from actual observations of individual water-power conditions extending over a series of years.

It will be profitable to explain, very briefly, these reconnaissance methods for estimating water-power. First, the area of the watershed in question is ascertained by measurement from the best available

maps; to this area is applied an *assumed* run-off coefficient such as would be suggested by a general knowledge of the precipitation, and of the topography, and other characteristics of the territories involved. The wise choice of the coefficient used will, of course, depend upon the good judgment and knowledge possessed by the engineer. This run-off coefficient, as it is termed, is a quantity which represents the amount of water that may be drained off any specified area during a stated period, and is usually expressed as so many cubic feet per second per square mile. Obviously, if the area of a watershed is known to be so many square miles, and each square mile, under specified conditions, will yield so much water, then the total yield of water from the whole watershed will be the product of the factors just mentioned.

When the discharge of a stream, or river, is actually measured, it is usually accomplished by means of floats, or by using a current-meter. The principles involved are very simple. They consist essentially of measuring the velocity of the flow of the stream by means of floats, or meter, and measuring also the area of the cross-section of the river at the place for which the velocity has been thus obtained. The volume of the water which passes a given point is the product of the area of the cross-section of the stream and the velocity of flow at that point.

A concrete illustration will make these methods of estimating clearer. Take, for example, the case of a water-power like Healey Falls, on the Trent River, Ontario. The fall is here considered to have an effective head of 60 feet, and we will further suppose that it is desired to ascertain the horse-power available at low water. From the map of the district it would be ascertained, by measurement, that the drainage area above the fall is about 3,630 square miles. If the engineer had previously ascertained that the run-off in some other similar territory was .4 cubic feet per second per square mile, he would use this coefficient and thus obtain an *estimated* run-off, or discharge, of 1,452 cubic feet of water per second (3,630 square miles x .4). Assuming water-wheels of 80 per cent. efficiency, this 1,452 cubic feet of water per second, with a fall of 60 feet, would give approximately 8,000 horse-power. If actual, yet insufficient, discharge measurements were made at Healey Falls, such data would be criticized by the engineers, according to the time of the year at which they were made, etc., in order to deduce what the Trent River would discharge at its lowest stage; and this quantity, so derived, would then serve as a check upon the flow estimated by means of the previously assumed run-off coefficient and drainage area.

ESTIMATING THE HORSE-POWER.

The theoretical horse-power available at any point on a stream is the product of the effective height through which the water falls, and the weight of the water falling in a given time. Thus:

Let Q represent the flow of water in cubic feet per second,
h represent the effective fall in feet.

Horse-power $\frac{5\,Qh}{44}$

Considering a good turbine to develop 80 per cent. of the theoretical power, we have

Horse-power $\frac{Qh}{11}$

Hence a simple rule for estimating the horse-power that may be developed under favourable conditions is: *Multiply the flow in cubic feet per second (Q) by the effective head in feet (h), and divide the result by 11.*

It must not be forgotten that, in order to state in a reliable manner the power available for any place, it is necessary to give the stage of the river (namely, the height of the surface of the river with respect to a zero or bench-mark), at which the amount of power stated may be produced.

CERTAIN DATA INDISPENSABLE

When the data collected is published it will be presented in *tabular* form, so as to be convenient for ready reference. The information communicated by engineers and others should, therefore, always be of a character that permits reduction to tabular form. The essential facts required to be known in every instance are:

(1.) Name of river upon which the fall, rapid or canyon is located:

(2.) Local name of fall, rapid, or canyon:

(3.) Description, giving location of fall, rapid, or canyon (if adjacent to a branch of a stream, state definitely whether power-site is on main river or on the branch, *and where*):

(4.) What total head in feet is obtainable at the site mentioned, and how is the head made up? That is, what portion of the head is direct fall, what portion rapids, and, about, in what distance does the drop, or fall, in any particular rapid occur?

(5.) How is the head measured?

ILLUSTRATION OF SUITABLE DATA

The fuller and more complete the information the better.

The fact is recognized that the filling-in of forms* is sometimes perplexing. The form given below, therefore, has been filled in with a suppositious set of replies in order to represent, in a very general manner, the character of replies that are desired in connection with the investigation.

*For convenience, forms corresponding to that given below have been prepared for British Columbia for the use of engineers and others. These blank forms may be had upon application to the Department of Lands, Victoria, B.C.

Date: Sept. 1, 1912.
Name of Informant: John A. Smith.
Address of Informant: Smith, P. O. (Smith Co.) B.C.

1. Name of river upon which the fall, rapid, or canyon is located.	Smith River.
2. Local name of fall, rapid, or canyon. (Please print this name in order to ensure correct spelling of same.)	SMITH CANYON FALLS.
3. Description, giving location of fall, rapid, or canyon. (If adjacent to a branch of a stream, state definitely whether power-site is on main river or on the branch, and where.)	The falls are situated on the main Smith River, about ½ mile below head of the canyon. Head of canyon is about 7 miles above Smith Post Office. Jones Creek enters about ½ mile above the falls.
4. What total head in feet is obtainable at the site mentioned, and how is the head made up?	Total 80 to 100 feet. There is a direct fall of 45 to 50 feet; and there is a drop in the rapids above the falls of about 20 feet in about a length of 1,000 feet. Below the falls there is a drop of about 20 feet in ½ mile.
5. How was this head ascertained?	Height of falls was measured with tape-line. Drop in the upper rapids was estimated, but I believe it is not exaggerated. Drop in lower rapids taken with hand-level.
6. What is the volume of water in the stream in miners' inches, or cubic feet per second.	John A. Smith took a measurement on May 24, 1912, and found 5,000 miners' inches.
7. What is the character of the banks?	High rocky banks. Right-hand bank (going up-stream) is perpendicular. Left-hand bank slopes back about on an angle of 45 degrees.
8. How high are the banks?	About 60 feet above crest of falls.
9. How wide is the river or canyon?	About 15 or 20 feet at canyon. Above canyon river widens out to 100 feet or more.

10. At about what period of the year does the stream above mentioned give marked evidence of its approach to low-water conditions?	Usually by the end of October.
11. When does *extreme* low-water period begin?	During January or February.
12. Does the stream ever go dry? If so, for how long a period?	It goes very low, and is practically dry from, say, the middle of January until the beginning of March.
13. Do you know if the stream is glacier-fed?	It is, but on the north branch only.
14. In your locality, do you know of any small mountain lakes or sites suitable for reservoirs that are not shown on the maps? If so, what are the local names (if any) and where are the lakes located?	There is said to be a lake about 1 mile long and about ½ mile wide, known as Smith Lake, at an altitude of 1,500 or 2,000 feet above Smith P. O. The lake is about ¾ mile to the N. E. of place where the trail leaves the river above Smith P. O.
15. Do you know of any possible reservoir-sites?	I have heard there is good storage possible above the upper canyon, which is about 15 miles above Smith P. O.
16. Are there any saw or other mills in your locality driven by water?	Brown's sawmill, situated on Brown Creek, about ¼ mile from the mouth.
17. Are there any mining companies using water under "head" in your locality?	The Smith Mining Co. had a small dam on Jones Creek near Jonesville; site is abandoned.
18. If there are photographs of the falls or rapids to be bought, please give address of the dealer and the price asked for them.	Robinson & Co., of Jonesville, have a photo of Smith Canyon Falls, which they will sell at $1.

REMARKS

Mr. A——— B————, living at Smith P. O., knows the lower Smith River. I understand there are falls on the right-hand branch of the Brown River. Mr. C——— D————, of Brown P. O., may know about these. The north branch of this river will be required for irrigation purposes.

Re Question No. 17: I think Mr. E——— F————, of Jonesville, P. O., knows of some other companies.

HOW CERTAIN DATA MAY APPEAR WHEN PUBLISHED

The following short table is given in order to show more clearly the form which the water-power data, when published will take. Columns B and D are deduced by office methods. Columns A, C, and E are the only ones required from field observers.

A—*Site.* Name of River and local name of Power-site.	B Approximate Area of Water-shed (in square miles).	C Approximate Head (in feet).	D Estimated Low-water Horse-power.	E REMARKS.
SMITH RIVER				
First Fall.........	616	12	925	Developed for sawmill.
Second Fall.......	616	14	1080	Old 8-ft. dam here for log-driving.
Cook Mill Dam....	612	19	1400	Saw- and grist-mill, 14 ft. developed.
Jones Rapids.....	590	14	1000	Rocky banks. Bank on south side low (not over 20 ft); not developed.
Foot of Jones Lake	520	15	980	Fall in rapids here of 5 ft.; 15 ft. head could be created. Good rocky banks about 20 ft. high.
Granite Canyon....	300	65	2500	Direct fall of 30 ft. at head of canyon; 35 ft. fall in 2,500 ft. of rapids.
Island Rips.	135	10	155	10 ft. in 1,500 ft. of rapids. Good dam-site. Rocky bluffs 50-60 ft. high; might possibly get 40 ft. head. Possible pondage above.
Falls....	130	300	4500	This is from outlet of Smith Lake, which could be diverted into Smith River by fluming around or tunnelling Smith Mountain. The 300 ft. could be obtained in under 3 miles. Level of Smith Lake might be raised 15 to 20 ft.

PRECISION REQUIRED IN GIVING LOCATIONS

A small sketch should always be supplied showing any particular portion of the river, and indicating, by an arrow-head, just where each respective power-site is situated. Care must be exercised to indicate whether the site is on the main stream *above*, or *below*, the mouth of any tributary which may be adjacent to the power-site. If the power-site is on a tributary it should be so indicated. Thus in the accompanying sketch (1), (2), (3), (4), and (5) would clearly indicate each of five sites.

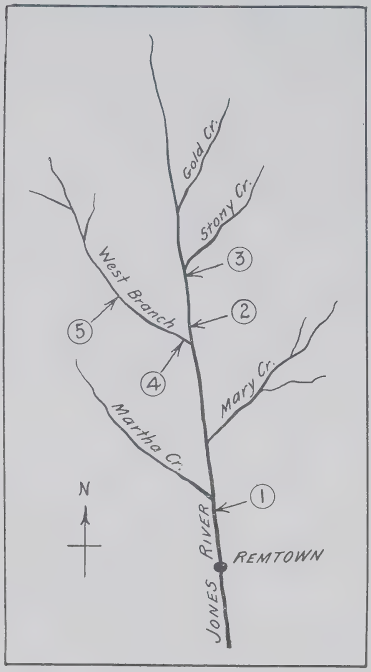

Figure: Diagram representing the respective locations of various supposed water-power sites.

Thus:

1. Remtown Fall.
2. Lower Jones Fall.
3. Upper Jones Fall.
4. West Rapid.
5. Nugget Fall.

DISCHARGE MEASUREMENTS

As has been explained above, it is necessary in connection with water-power and irrigation projects to possess all possible knowledge respecting the flow of streams. Isolated measurements are practically useless, unless the stage of the stream at the time at which the flow measurement is made be known. The stage of the stream should be referred to some one or more permanent bench-mark or bench-marks, the location of which should be plainly described. *Measurements of discharge made at the lowest and flood stages are of especial value.*

THE GAUGE

The gauge may consist of an instrument, graduated scale, or other device, whereby the stage and changes in stage of the water surface are observed or recorded. This fluctuation is measured with

reference to a fixed bench-mark or datum, to which the position of the gauge must maintain a constant relation.* The many styles of gauges in use all belong to two classes—recording and non-recording. We shall here, however, refer only to one type of the non-recording class—staff-gauges.

Staff-gauges. — Fixed staff-gauges may be either vertical or inclined. They have the advantage of certainty in datum so long as the gauge is undisturbed, small first cost, and simplicity in reading. They have the disadvantage of being liable to disturbance, or destruction by frost action, or by floating ice, logs, or drift. The requirements for a satisfactory gauge of this type are (1) that the graduations be both clear and permanent; (2) that the gauge be easily accessible to read; (3) that it be stable.

The vertical staff is the better of the two, where there is available, either in or over the water, an artificial or natural object, having a vertical face to which the gauge may be attached. Such object may be a bridge, abutment, or pier, a wharf, a tree, or a rock.

The best form of vertical gauge consists of a base of rough 2-inch by 4-inch, or 2-inch by 6-inch plank, to which a lighter plank, having the graduated face, may be easily fitted and nailed, with the zero at the desired elevation. The graduated plank will be found satisfactory if made in about 5-foot sections of $\frac{7}{8}$-inch by 4-inch pine, painted white, with graduations cut as V-shaped notches painted black. This facing and graduation is cheaply made and easily installed, and the graduations are reasonably permanent. The graduation should be in feet and tenths (and in some instances hundredths) of a foot.

The inclined gauge is useful where there is no existing object to which a vertical staff may be attached. It should be made of 4-inch by 4-inch timber, supported at short intervals by posts firmly set in the ground, and should be graduated by level after being placed in position, so as to give the reading directly. Such gauges are especially liable to change of datum and should be frequently checked in elevation at several points.

In some instances it may be arranged to have staff-gauges installed, in which event the description just given will be of service.

*The gauge, wherever possible, should be so placed as to have the graduations reach at least to the lowest stage to which the water surface may drop.

STREAM DISCHARGE

The discharge measurement of a stream requires the determination of the area of its cross-section and the velocity of its moving water. For a general discussion of the laws governing and methods used in determining these two factors, reference must be made to some of the various publications which treat upon this subject.*

The particular methods employed will depend, primarily, on whether the velocity is determined by current meter, float, or slope measurements.

The most convenient, and generally the most satisfactory, method of making measurements of stream-flow is by means of a current-meter. Yet, in attempting, at the present time, to secure reconnaissance data respecting possible water-powers, it is probable, where measurements of stream discharges are made in isolated territory, that such discharges, for the most part, may be ascertained by means of surface floats. Therefore, there will be given below, in some detail, an explanation of this means of measuring stream-flow. However, before discussing float measurements it will be advisable to set forth, very briefly, certain data appertaining to measurements made with current meters.

AREA OF CROSS-SECTION

The first factor in measuring discharge—the area of the cross-section of a stream—depends on the contour of the bed. This is determined by soundings, taken with reference to the stage of the river as observed on the gauge.

For current-meter stations the area of only the measuring section is required.

For float and slope stations the average area throughout the portion of the river used for the observations must be obtained. The areas of the ends of the section, and at several intermediate points, are measured, and their average is then assumed to be the mean area.

SOUNDINGS

Soundings are made either by a graduated rod or by weight and line.

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*For representative examples of methods, and reports of investigations respecting water-power resources, reference may profitably be made to various publications mentioned on pages 19-20 of *The Water Powers of Canada*, Ottawa, 1911; also to such works as *River Discharge*, by J. C. Hoyt and N. C. Grover, New York, 1908 (here quoted); also, *A Treatise on Hydraulics*, by H. J. Hughes and A. T. Safford, New York, 1911; also, *Irrigation Engineering*, by H. M. Wilson, New York, 1909.

Sounding rods are limited in use to depths of less than 15 feet. They are best adapted for use at wading and boat stations, where the depths and velocities are relatively small. Rods may occasionally be used at bridge stations where the bridge is not high above the water.

The weight and line are used in making soundings in water of greater depth than 15 feet, and from bridges or cables which are high above the water. Soundings from a bridge, or cable, with weight and line are most readily taken as follows: Lower the weight and line until the weight rests on the bed of the river directly underneath the the measuring point. With the line taut, mark a point on it opposite a fixed point on the bridge or car; then raise the weight until it just touches the surface of the water and measures the length of the sounding-line that passes the fixed point mentioned above. The depth is most readily measured by placing the end of a linen or metallic tape opposite the fixed starting-point on the sounding-line, grasping both the line and the tape in the hands, and drawing up the line and tape without permitting them to slip on each other until the weight rests on the surface of the water. The length of line thus drawn up, representing the depth of the water, can then be read directly from the tape. This measurement may usually be made by one person, even when the depth is 10 to 20 feet. Where meter measurements are made from a bridge or cable, the meter cable, with meter and lead attached, is generally used for sounding if the depths and velocities are small, and if boulder bottoms are not a menace, but care must be taken that the meter is not thereby damaged.

The greatest, and the most common, errors in measurements of discharge are caused by erroneous soundings. Errors in soundings by weight and line are due to the weight being carried down-stream, so that it does not fall immediately below a point perpendicularly beneath the measuring-point, or sometimes, to the bowing of the line. Both these causes make the soundings too great. Errors in soundings with rods are due to the rod not being perpendicular, to the water raising on the rod, and to the rod sinking in the bed. In order to verify the accuracy of soundings made at medium or high stages, they should be compared with those taken at low water.

STANDARD CROSS-SECTION

For gauging stations on streams whose beds are permanent or nearly so, a standard cross-section should be constructed from careful soundings. This cross-section should be referred to the zero of the gauge and to some reliable bench-mark, so that the depths for any

stage can be seen by adding the gauge height to the depths below the zero of the gauge.

The soundings for a standard cross-section should be taken close enough together to develop all irregularities in the cross-section. Standard cross-sections have three uses: (1.) They serve as checks on future soundings; (2) they indicate changes which may occur in the bed of the stream; and (3) they may be used in determining the area for measurements taken at times when it is impossible to make soundings on account of high water or other conditions.

The soundings and gauge heights should be recorded in feet and tenths, or hundredths of a foot.

CURRENT-METER MEASUREMENTS

In making a current-meter measurement, the cross-section is divided into partial areas, varying in width from 2 to 20 feet, depending on the size of the stream. These partial areas are bounded by perpendiculars terminating at points in the surface known as measuring-points, so-called, because they indicate where the observations of depth and velocity are taken. These points should be so spaced as to show any irregulaties, either in the cross-section or in the velocity.

When measurements are made at bridge or cable stations, the measuring-points should be permanently marked on the bridge rail or floor, or on the cable, and used for successive measurements of discharge. When measurements are made at boat and wading stations, the points will be indicated by the graduations on the tape or tagged line, which is generally stretched at the time of each measurement. A cable station is represented by the accompanying figure.

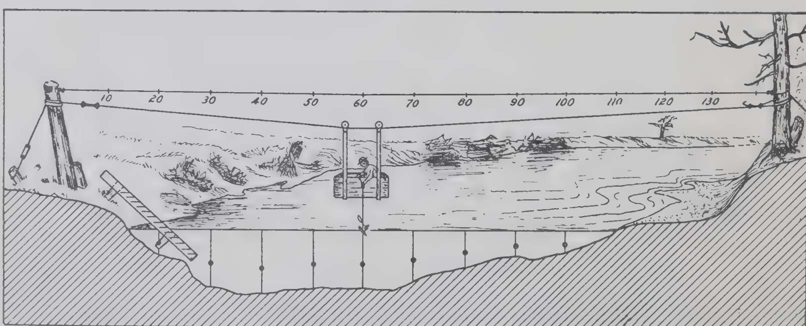

Figure: Representing, diagrammatically, a cable river metering station, and showing conventional unit areas as being metered at .6 of the depths at the respective measuring-points.

For each of these sections the discharge is determined, independently, by multiplying its mean velocity by the area. The total discharge is the sum of the partial discharges. This computation of partial discharges eliminates the distribution of conditions existing in one part of the channel to parts in which they do not apply.

When a current-meter is employed, the velocity at a measuring point may be ascertained by any one of several methods. These methods which are known as: (1) the velocity-curve method, (2) the .6-depth method, (3) the surface method, (4) the two-point method, (5) the three-point method, and (6) the integration method, may briefly be explained as follows:

Vertical Velocity-curve Method.—By the vertical velocity-curve method, measurements of horizontal velocity are usually made just under the surface, at .5 foot below the surface, and at each fifth to each tenth of the depth, from the surface to the bed of the stream. These measured velocities, when plotted, define for each such observation point the vertical velocity-curve from which the mean velocity in that vertical is determined.

The vertical velocity-curve method is valuable as a basis for comparison for all other methods, for determining coefficients to be used in reducing values obtained by other methods to the true value, for use under new and unusual conditions of flow, and for measurements under ice. The method is not, however, in general use for making observations of velocity for routine discharge measurements, because the increased accuracy thereby obtained is frequently overbalanced by errors arising from change in stage of the stream during the longer time required for the measurement.

The .6-depth Method.—In practical measurements of stream discharge it is necessary to determine the horizontal velocity in a large number of verticals. Therefore it is usually most satisfactory to employ a method which requires not more than three velocity observations to be made in each vertical. If only one point is used, it is desirable that it be in such a position that the use of a coefficient to determine the mean velocity is not necessary. From experiment it has been ascertained that such a point lies approximately at .6 of the depth of the stream. This method is applicable over a wide range of conditions, is easy of execution, and is reasonably accurate for normal flow in the straight reaches of all streams, except very deep and very shallow ones.

Many experiments have shown that the thread of the mean velocity lies between 56 per cent. and 73 per cent. of the depth, with an average of 61 per cent. The error resulting from the use of .6 depth is very small, ranging from -6 per cent. to $+4$ per cent., with a mean of 0 per cent. *Therefore, in the .6-depth method it is assumed that the velocity of .6-depth is the mean velocity in the vertical; and the meter is held at that point in this method.*

Although this method is intended to be used without coefficients, yet it may be found, by vertical velocity-curve measurements, that a coefficient is necessary in some instances to reduce the observed velocities to the mean.

The Surface Method. — The surface method is used in the measurement of velocities of swift streams, especially at times of freshet, when it is impracticable to sink the meter much below the surface. Therefore, the observation of velocity is made at a point near the surface, but far enough below to eliminate any disturbance from wind or waves. The point of observation in this method should be from .5 foot to 1 foot below the surface, its location depending on the depth of the stream. The measured velocity must, however, be multiplied by a coefficient to reduce it to the mean. This coefficient, as determined by credible experiments, varies between 78 and 98 per cent., depending upon the depth of the stream and the magnitude of the velocity. The deeper the stream and the greater the velocity, the larger the coefficient. For average streams in moderate freshet a coefficient of about 90 per cent. will generally give fairly accurate results. In flood-work, coefficients of 90 to 95 per cent. should be used.

The Two-point Method. — The two-point method is used on streams in which the location of the point of mean velocity is uncertain, or when greater accuracy is desired than can be obtained by the .6-depth method. The mean of the velocities at .2 and .8 depth gives nearly the mean velocity in the vertical. Experiments show that this theory holds very closely in nature. Therefore, in this method the meter is held at .2 and .8 depth of each vertical.

The Three-point Method. — The three-point method approaches more nearly the vertical velocity-curve, and is used for obtaining greater accuracy than is possible by the one and two-point methods. In this method the meter should be held .2, .6, and .8 depth. The mean velocity is then obtained by dividing by 4 the sum of the velocities measured at .2 and .8 depth plus 2 times that at .6 depth.

The Integration Method.—The integration method is used both for obtaining the mean velocity in the vertical and also the mean velocity in the entire cross-section of the stream.

In determining the mean velocity in the vertical, the meter is moved at a uniform speed from the surface of the water to the bed of the stream and return, and the revolutions and time are observed. The meter thus passes successively through all velocities in that vertical, and the resulting observations determine the mean in that vertical. The method is valuable for checking other methods, but generally requires the service of at least one more man to observe time, as the engineer must be occupied with the movements of the meter. It is consequently not so commonly used as the point methods. The Price meter is not suited to observations by this method, as the vertical motion of the meter causes the wheel to revolve. The Haskell meter, on the other hand, may be moved vertically, swiftly and slowly, with no effect on the wheel.

In determining the mean for the entire section, the meter is moved with uniform speed throughout the section, usually in a zigzag path extending from surface to bottom, and from side to side of the section.

FLOATS

When floats are utilized for the direct measurement of the velocity of streams, those in common use are surface, subsurface, and tube- or rod-floats.

Subsurface-floats.—The subsurface-float is designed to measure velocities below the surface and may be made to float to any depth. By arranging the submerged float at the depth of mean velocity, it may be utilized in observing mean velocity directly. Allowance must be made, however, for the accelerating effect of the attached line and surface-float.

Tube- or Rod-floats. — The tube- or rod-float is designed to measure directly the mean velocity in a vertical. It is generally a cylinder of tin, about 2½ inches in diameter, weighted at its lower end and plugged with wood or cork at its top. Small extra weights to make it float at the exact depth desired may readily be added by admitting water or by putting in shot. The tube should be graduated, and alternate feet painted black and red in order that the depth of the flotation may readily be observed.

A number of tubes, of different lengths, are necessary for measuring the velocity at different depths in an ordinary cross-

section. A float of this type, consequently, is best adapted for use in artificial channels in which the depth is nearly uniform. Natural channels are generally too rough and too variable to permit of satisfactory use. In field-work, where it appears expedient to employ rod-floats, these may be improvised by using dry saplings, cut to suitable lengths and weighted with stones tied to their lower ends.

Although designed to measure directly the mean velocity in a vertical, the tube cannot be made to float in contact with the bed of the stream, and, consequently, it does not receive the effect of the slowest moving water. The rougher the bed the greater the error in this respect. A factor less than unity is, therefore, necessary to reduce the observed velocity to the mean.

MEMORANDA REGARDING THE DETERMINATION OF APPROXIMATE STREAM DISCHARGE BY SURFACE-FLOATS *

Although the method of determining the discharge of streams with floats is not usually so convenient, or simple, as with the current-meter, it is, however, less expensive, and for all practical purposes, especially in reconnaissance work, the results are quite as good as those obtained with the current-meter, provided the measurements are not to be used in conjunction with daily gauge heights in order to determine the daily discharge.

To determine the discharge by means of floats, select a straight course along the stream in question, the length of the course being, roughly, about twice the width of the stream. The cross-section throughout this course, and for a short distance above and below it, should be as uniform as possible; and the bottom should be as smooth as possible and free from all large projections. Rather than run floats over bad reaches in the stream, it is preferable to shorten the course, although it is rarely desirable to take a course less than 50 feet in length, unless the stream is less than 10 to 20 feet wide.

At the upper end of the course set two rods, rod 1 on the river bank, and rod 2 about 50 to 100 feet back from the river, so that a line through them will be, as nearly as possible, at right angles to the direction of the stream over the selected course. Carefully measure the distance from rod 1, located nearest the river, to the lower end of

* The data respecting stream measurement by surface-floats, here given, have been furnished as a result of special research made by Mr. R. H. Bolster, and have been made available, for present purposes, by the courtesy of Mr. M. O. Leighton, Chief Hydrographer of the United States Geological Survey.

the course, and there locate rod 3 at an equal distance back from the river. Going next back from rod 3 the same distance (measured) that rod 2 is from rod 1, locate rod 4, which should be exactly the same distance from rod 2 as rod 1 is from rod 3. *Note.*—In very narrow streams, rods 2 and 4 can frequently be dispensed with, but in wide streams they should always be used.

Have an assistant loosen floats,* consisting of small blocks of wood (weighted, if necessary, to avoid wind effect on the surface exposed above the water), a short distance above the upper end of the course, spacing them across the stream at intervals of about one-tenth the width of the river. Sight past rods 2 and 1 and note, with a stop-watch,† or an ordinary watch, the time when a float passes the upper end of the course. Go to the lower end of the course and similarly note the passage of the same float past staffs 3 and 4. The average of time the float runs, divided into the distance apart of the upper and lower ends of the course, will give the average *surface* velocity in feet per second.

Determine four cross-sectional areas (or more if desired), located at $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$ the distance between the upper and lower ends of the course. Stretch a tagged telegraph wire, measured cord, or steel tape across the river at the points indicated, and, at regular intervals, take soundings, recording them as indicated in the table below. Ten sounding points, equally spaced, should ordinarily be sufficient.

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* A corked-bottle float, with a flag in the top and a weight in the bottom, makes a very satisfactory surface-float, as it is but little affected by the wind. In flood measurements good results can be obtained by observing the velocity of debris, or of floating cakes of ice.

† Stop-watches are necessary for the satisfactory observation of velocity by floats, and for integration by meters. They are recommended for use in all meter-work.

CROSS-SECTION ONE-EIGHTH BELOW UPPER END OF COURSE

Station.	Depth in Feet.	Width in Feet.	Mean Depth in Feet.	Area in Square Feet.
12	0.	..	...	...
20	1.1	8	.6	4.8
30	4.3	10	2.7	27
40	5.6	10	5.0	50
50	6.3	10	6.0	60
60	7.6	10	7.0	70
70	7.0	10	7.3	73
80	6.1	10	6.6	66
90	5.3	10	5.7	57
100	4.0	10	4.6	46
110	2.1	10	3.0	30
117	0.	7	1.0	7
			Total area,	491

Total area at $\frac{1}{8}$ point	491
" " $\frac{3}{8}$ " (here assumed to be)	500
" " $\frac{5}{8}$ " " "	458
" " $\frac{7}{8}$ " " "	511
Total	1,960
Average cross-section.......	490 square feet.

The average of the four areas can be taken as the average cross-sectional area of the course. The soundings can be made by wading the section with a graduated rod, or from a boat with graduated rod, or with weight on the end of a graduated cord, if too deep for wading. The tagged wire can be used to hold the boat in position.

The mean surface velocity (feet per second) x the mean cross-sectional area (square feet) x a constant K = the discharge of the stream in cubic feet per second.

The constant K varies quite widely under different channel conditions, ranging from a minimum of about .70 to a maximum of about .90 or more. In general K can be said to vary inversely as the slope (or velocity), inversely as the roughness, directly as the depth and indirectly as the width (for narrow streams).

The following table will serve as a rough guide in the determination of the most probable coefficient K. Interpolate for conditions not given in the table.

Velocity (Feet per Second).	Average Depth (Feet).	Size of Material on Bottom (Feet).	Coefficient.
2 or less	2 or less	½ or less	.80 to .85
2 "	2 "	1	.75 to .80
5	2 "	½	.80
5	2 "	1	.75
10 or more	2 "	½	.75
10 "	2 "	1	.70
2 or less	5	½ or less	.85 to .90
2 "	5	1	.85
2 "	5	3 or more	.85
5	5	½ or less	.85
5	5	1	.85
5	5	3 or more	.80 to .85
10 or more	5	½ or less	.80 to .85
10 "	5	1	.80
10 "	5	3 or more	.80
2 or less	15	½	.90
2 "	15	1	.90
2 "	15	3 or more	.90
5	15	½	.90
5	15	1	.90
5	15	3 or more	.85 to .90
10 or more	15	½	.90
10 "	15	1	.85 to .90
10 "	15	3 or more	.85 to .90

The coefficient close to abutments, or piers, usually lies between .90 and 1.00, and is often greater than unity. Similarly for channels with rectangular sides and a width not greater than about three times the average depth, the coefficient is likely to be higher than .90 and sometimes greater than unity.

CONVENIENT EQUIVALENTS

The following is a list of convenient equivalents for use in hydraulic computations:

In British Columbia, under the "Water Clauses Consolidation Act, 1897," section 143, one miner's inch was declared to be a flow of water equal to 1.68 cubic feet per minute.

Therefore, one miner's inch = .028 cubic feet per second, and one cubic foot per second = 35.7143 miners' inches, approximately.

A flow of one miner's inch per second = 0.1745 imperial gallons per second.

1 second-foot equals 40 California miners' inches (law of March 23, 1901).

1 second-foot equals 38.4 Colorado miners' inches.

1 second-foot equals 40 Arizona miners' inches.

1 second-foot equals 7.48 United States gallons per second.

1 second-foot equals 6.2321 imperial (British) gallons per second.

1 second-foot for one year covers 1 square mile 1.131 feet, or 13.572 inches, deep.

1 second-foot for one year equals 31,536,000 cubic feet.

1 second-foot equals about 1 acre-inch per hour.

1 second-foot for one day covers 1 square mile 0.03719 inch deep.

1 second-foot for one 28-day month covers 1 square mile 1.041 inches deep.

1 second-foot for one 29-day month covers 1 square mile 1.079 inches deep.

1 second-foot for one 30-day month covers 1 square mile 1.116 inches deep.

1 second-foot for one 31-day month covers 1 square mile 1.153 inches deep.

1 second-foot for one day equals 1.983 acre-feet.

1 second-foot for one 28-day month equals 55.54 acre-feet.

1 second-foot for one 29-day month equals 57.52 acre-feet.

1 second-foot for one 30-day month equals 59.50 acre-feet.

1 second-foot for one 31-day month equals 61.49 acre-feet.

1 inch deep on 1 square mile equals 2,323,200 cubic feet.

1 inch deep on 1 square mile equals 0.0737 second-feet per year.

1 foot deep on 1 square mile equals 0.88 second-feet per year.

1 mile equals 5,280 feet.

1 acre equals 43,560 square feet.

1 acre equals 209 feet square, nearly.

1 cubic foot of water weighs about 62.5 pounds.

1 horse-power equals 550 foot-pounds per second.

1 horse-power equals 746 watts.

1 horse-power equals 1 second-foot falling 8.80 feet.

$1\frac{1}{3}$ horse-power equal about 1 kilowatt.

To calculate horse-power quickly: $\frac{\text{Sec.-ft. x fall in feet}}{11}$ = net horse-power on water-wheel realizing 80 per cent. of theoretical power.